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**THE EFFECT OF FATIGUE UPON SONAR
DETECTION**

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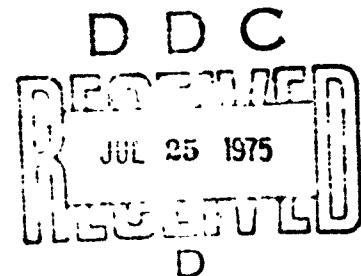
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SUMMARY

Many vigilance experiments are not very relevant to sonar work. The most relevant experiments are listed in Table 1. In most experiments vigilance declines during the watch, even after fairly prolonged practice at the task.

The decline in vigilance can be prevented if identical artificial signals are injected when there are no real signals, and full knowledge of results is given on the artificial signals (Figure 1). Another method of maintaining vigilance is to provide the man with the assistance of a computer. If desired the computer can be programmed to inject artificial signals, and give knowledge of results on them, when it detects no true signals.

Table 2 lists the effects of mild stresses upon vigilance. A sleep debt of about 5 hours reduces vigilance. With enlisted men, vigilance is low at the start of the working day, and after a heavy meal. A cabin which is rather too warm for comfort may help to increase vigilance. So may extraneous noises.



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Vigilance experiments and sonar detection

Sonar work

1. Sonar work can be described using the parameters of vigilance experiments. It involves prolonged and repeated work sessions, with very few signals and inadequate knowledge of results. Visual search may or may not be involved.
2. The sonar man has to work a number of hours every day trying to detect targets. Usually there are few ships close enough to be detected. There may be few or no targets during a complete watch.
3. When a target is detected, the officer of the watch may not know whether there is a ship in the vicinity. So he cannot always state confidently that the sonar man is correct in his detection, or that he has made a false detection. Perhaps more important, when an obvious target is not reported, the officer of the watch often does not know that an obvious target has been missed. Thus the sonar man has no clear idea of how well or badly he is performing.
4. Visual search is not required when a sonar man works with the output of a single channel, whether it is displayed to his ears or to his eyes. Visual search is essential with present day sonar systems, where the man receives the outputs of a number of channels. In future systems, a computer may be able to mark the areas of the display for the man to look at. Here visual search will cease to be quite such an important aspect of sonar detection as it is in present day sonar systems.

The most relevant vigilance experiments

5. The most relevant vigilance experiments involve repeated prolonged work sessions, without knowledge of results on the success of detections. Examples are the 2 week watchkeeping experiments carried out at MRC APU, which are summarized by Colquhoun, Blake and Edwards (1969b). These and the other most relevant experiments are listed in Table 1.
6. All the experiments in the table have more signals than a sonar man usually receives. This is because more signals supply the experimenter with more data, and so improve the reliability of his results. The experimenter strikes a compromise between presenting few enough signals for the task to be a vigilance task, and presenting sufficient signals to provide an adequate amount of data on performance. There is one experiment in the table with only 1 signal per 1 hr session (Loeb and Binford, 1970). Even this represents 24 sonar targets in 24 hours.
7. Column 5 of Table 1 shows that most of the experiments have brief signals. The chief exceptions are the experiments by Adams (Adams, Humes and Sieveking, 1963; Adams, Humes and Stenson, 1962) and by Wallis and Samuel (1961). Here the signals last respectively up to 20 sec and up to 60 sec. It might be thought that brief signals are not representative of visual sonar displays, because the phosphor persists for seconds or even perhaps for a minute. This is not necessarily so, even with a persistent phosphor.
8. Brief signals can be regarded as representative of visual search tasks. This is because if the man does not happen to be attending during his brief glance at a particular display area, he will miss a signal in this area, unless he has another look later on. Brief signals are also representative of listening to a sonar which rapidly

scans a wide angle, because the signal from a target somewhere in the area lasts only a second or two. If the man is not attending during the critical second or two, he will miss the signal. The signal may not be repeated on the next sonar scan if the submarine from which it comes disappears into the shadow zone.

9. Column 7 of Table 1 shows that the experiments by Adams and by Wallis and Samuel involve visual search. This makes the long lasting signals they use comparable to the brief signals used in the remaining experiments. The major discrepancy is the auditory task used by Wallis and Samuel. Here the auditory signals are increased in intensity until they are detected. If this task were representative of sonar work, fatigue would not be a problem, because a signal would always be detected once it had a large enough signal to noise ratio.

Other vigilance experiments

10. The vast majority of vigilance experiments (see Davies and Tune, 1970) are not listed in Table 1. Many of the experiments involve a short practice followed by a single experimental session. These experiments are not included in the table because the man is not sufficiently practised at the task. In some experiments part or all of the expected decline in vigilance during the experimental session is masked by the improvement with practice at detecting signals (see Poulton, 1960).

11. In other vigilance experiments each man is presented with a different experimental condition in each session. The order of conditions is balanced for the group of men serving in the experiment, by using a latin square design. For example the number of signals may be varied from session to session.

12. The difficulty with experiments of this kind is that the results may apply only to people who have been trained on all the signal frequencies used in the experiment. The results do not necessarily apply to people who have always received only a small number of signals per session. The results are likely to be biased by range effects, and by transfer effects between one signal frequency and another (Poulton, 1973).

13. There can be similar difficulties of interpretation if an intensive practice with many signals precedes a vigilance session with few signals. At the start of the vigilance session the man tends to respond more frequently than he should, because he has been responding more frequently during the practice. Using this strategy, he starts by detecting a high proportion of signals. But he makes a large number of false detections (Colquhoun and Baddeley, 1964). This depresses the overall quality of his performance as measured by d' (an index of the ability to detect signals). Probability matching is discussed in greater detail later in the review.

Uncomplicated fatigue

The decline in vigilance after fully learning a task

14. Columns 8 and 9 of Table 1 show the duration and number of work sessions in vigilance experiments with many sessions. The right side of the table shows whether there are changes in performance during work periods towards the end of the number of sessions listed in column 9. Of the 31 entries where results are available, a decline in vigilance during the task certainly or probably occurs in all except 7. The 7 exceptions are each indicated by an underlined No.

15. A failure to show a reliable decline in vigilance during the task does not prove that there is no decline. An unreliable result may be due to using too few people in the

experiment, or be too much variability in performance. For 4 of the entries in the table which do not show a reliable decline in vigilance (C H Baker, 1953; Carpenter, 1946; Colquhoun and Edwards, 1970) there is nothing sufficiently unusual about the experiments to explain why vigilance does not decline reliably during the session. If the distribution of the average measured decline in the 30 or so experiments is plotted the results of the 4 experiments may simply be found to lie in the tail of the distribution, where the sizes of the measured declines in vigilance approach zero

16. However there are good reasons for the other 3 exceptions, which are discussed later in the review. In the Hartley, Olsson and Ingleby (1972) experiment the man receives computer assistance. In both the Wallis and Samuel (1961) conditions the man receives immediate knowledge of results. When a signal is reported, it is acknowledged by the experimenter, who turns off the signal.

17. In most of the experiments the decline in vigilance is less marked in the later sessions after learning the task, than it is in the earlier sessions before much learning has taken place. There are 2 reasons for this. First, in some experiments the initial one or more sessions are preceded by an intensive practice period with many signals. The man therefore expects frequent signals when he starts the session. Colquhoun and Baddeley (1964) show that this increases the number of detections at the start of the session. As a result, there is a greater decline during the course of the session. The intensive practice also increases the number of false detections at the start of the session.

18. The second reason for the greater decline during a session before fully learning the task, is that initially the task is novel and challenging. The man starts with an intense concentration, which he cannot maintain for the duration of the session. As his level of arousal falls during the session, his performance deteriorates.

19. The change in the level of arousal during the initial vigilance session is reflected in various physiological measures (Daniel, 1967; Davies and Krkovic, 1965; Eason, Beardsall and Jaffee, 1965; O'Hanlon, 1970; Wilkinson and Haines, 1970). The people who show marked physiological measures of arousal during an initial session, tend to detect more signals during the session than people who show less marked physiological measures of arousal (O'Hanlon, 1970; Poock, Tuck and Tinsley, 1969). However most of the changes in the physiological measures are barely reliable statistically. This is because people vary a good deal in the particular physiological measures which indicate their individual levels of arousal (Poulton, 1970, Chapter 2).

20. After a good deal of practice, the task ceases to be novel and challenging. The man then starts with a level of concentration which is not much above the level which he can maintain throughout the session. The decline in vigilance during the session is therefore smaller.

Immediate knowledge of results may prevent or reduce a decline in vigilance

21. In columns 10 and 11 of Table 1, knowledge of results is listed as immediate or delayed. With immediate knowledge of results, the man is usually informed at once when he correctly detects a signal, and when he makes a false detection. If a signal is not detected within a fixed short period of time, the man is told that he has missed a signal.

22. With delayed knowledge of results, the man is usually told after each session how many signals he has detected, how many he has missed, and the number of his false detections. His scores and those of his colleagues in the experiment may be posted on

a notice board for everyone to see. In some experiments immediate knowledge of results is combined with delayed knowledge of results. The combination is called by Wilkinson (1964) full knowledge of results.

23. It has already been suggested that immediate knowledge of results may have prevented the decline in vigilance in the experiment of Wallis and Samuel (1961). There is a suggestion in the experiment by Wiener (1968) that immediate knowledge of results may have reduced the size of the decline in vigilance within sessions after practice. If anything the undergraduates who always receive immediate knowledge of results show a smaller decline in detections during their last session with knowledge of results, than does the control group of undergraduates which is always without knowledge of results. But unfortunately Wiener does not report the statistical reliability of the difference.

24. A number of experiments compare immediate knowledge of results with no knowledge, using only 1 or 2 experimental sessions. Immediate knowledge of results is found to increase the number of detections and the speed of detections, and to reduce or eliminate the decline in vigilance within sessions. As already indicated, a difficulty about these brief experiments is that the man has not fully learnt the task. Immediate knowledge of results helps to teach the task. More rapid learning may alone account for the effect of immediate knowledge of results in such brief tasks. It cannot be deduced that immediate knowledge of results will have an equally beneficial effect once the task has been fully learnt.

Delayed knowledge of results and probability matching

25. In vigilance experiments, a number of sessions with delayed knowledge of results can produce behaviour known as probability matching. The man makes about as many responses during each session as he knows that there are signals. Of the experiments listed in Table 1, probability matching after practice is shown in the experiments of Buckner, Harabedian and McGrath (1960), Hartley, Olsson and Ingleby (1972), Hatfield and Soderquist (1969), and by Wiener's (1968) group with immediate knowledge of results.

26. If the man adopts the strategy of probability matching, he makes a relatively large number of false detections when he detects few signals. He makes relatively few false detections when he detects most of the signals. Thus d' (an index of the ability to detect signals) and g (an index of cautiousness) rise and fall together.

Full knowledge of results on additional artificial signals

27. It is not often possible to tell the sonar man when he has correctly detected a signal, or missed a signal. But Wilkinson (1964) points out that full knowledge of results can be supplied on signals which are injected artificially. Figure 1 from his paper illustrates the advantage of doing this.

28. The unfilled points show the proportion of detections of 8 real signals by a group of 6 enlisted men, who are given an additional 40 artificial signals on alternate sessions. On the 40 artificial signals the men receive immediate knowledge of results, and scores on these signals are posted on a notice board after each session. No knowledge of results is available on the 8 real signals. The artificial signals are identical with the real signals. The men are not told when an artificial signal will appear, as they are in the unsuccessful experiment by Wallis and Newton (1957). The filled points represent a control group of 6 men who never receive artificial signals, nor knowledge of results.

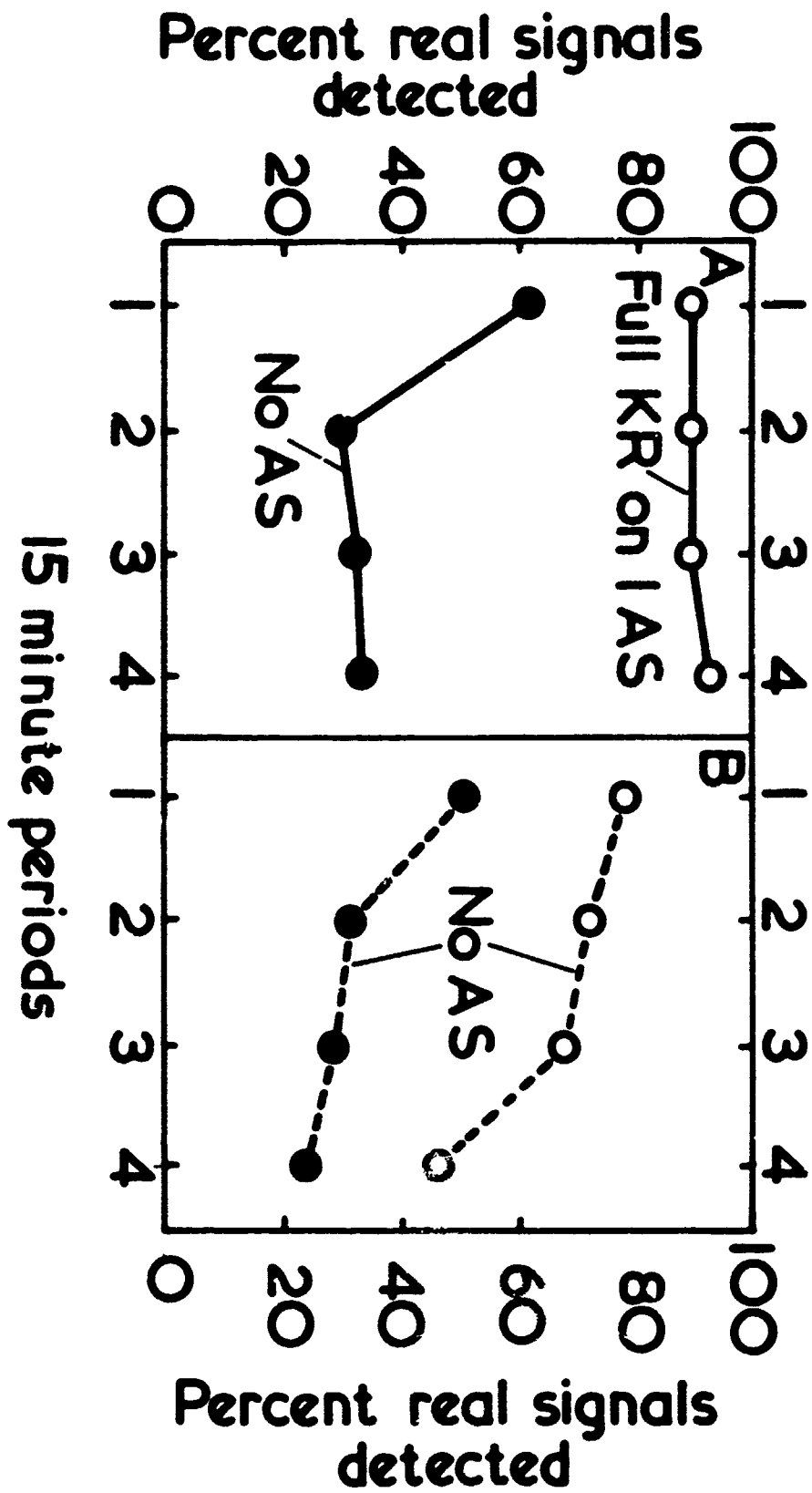


Figure 1

Figure 1. The effect upon the detection of real signals of injecting artificial signals (AS) and giving knowledge of results (KR) on them. A. Sessions 2, 3 and 6 with 40 artificial signals identical with the 8 real signals (IAS). B. Sessions 1, 4 and 5 with only 8 real signals (NoAS). The filled points represent the results of a control group which never receives artificial signals. (After Wilkinson, 1964).

The differences in height between the functions with filled and unfilled points are probably due to an initial difference between the 2 groups of men. In the very first session without artificial signals, the men who are to receive artificial signals make twice as many detections as the control group, and 5 times as many false detections. Both differences are statistically reliable. The results in the figure look much the same if the first 2 sessions are excluded on the grounds that the men are not then fully practised. The details of the experiment are listed towards the bottom of Table 1. For the group (not shown) with different artificial signals, the artificial signals last 0.67 sec.

29. The left side of the figure shows that in the one hour sessions with identical artificial signals and knowledge of results on them, vigilance on the real signals does not decline during the hour. Whereas with only the 8 real signals without knowledge of results, vigilance does decline. If an early session is excluded because the men are not fully practised, the decline in vigilance is statistically reliable.

30. The right side of the figure shows the results of the alternate sessions when the experimental group has only the 8 real signals. Here vigilance declines as much during the hour as it does with the control group which always has only real signals. Thus in this experiment it is necessary to continue to provide artificial signals if they are to be of the greatest benefit. It is not yet known whether this is necessary when only occasional artificial signals are injected.

31. Wilkinson (1964) runs 3 other experimental groups. The results of one group indicate that to be of greatest assistance, the artificial signals have to be identical with the real signals. The results of the other 2 groups indicate that to be of greatest assistance, full knowledge of results, both immediate and delayed, must be given on the identical artificial signals. Telling the man at once when he detects an artificial signal, or fails to detect an artificial signal, prevents part of the decline in detections on the real signals. But the decline is only fully prevented by also posting the scores on the artificial signals on a notice board after each session, and drawing the man's attention to his and his colleagues' scores. To get the best out of the man, his reputation among his colleagues as a sonar man must be made to depend upon his performance.

32. If results similar to those in Figure 1 are obtained with only occasional artificial signals, it will suggest a possible use for a computer which works in parallel with the sonar man. When the computer fails to detect any possible signals, it can be programmed to inject an artificial signal from a store of artificial signals, and to provide knowledge of results on it. This will help to keep the man alert when there are no real signals. It can also serve a useful function in training at sea, if the artificial signals are selected to be a representative sample of the likely signals, and vary in

signal to noise ratio.

Problems of operating with artificial signals

33. In using artificial signals mixed with real signals at sea, the principal problem is the appearance at the same time of an artificial signal and a real signal. This can happen if the computer does not detect the real signal, and so injects an artificial signal. If the computer subsequently detects the real signal, it can indicate this to the man, and hurriedly remove the artificial signal. But if the computer leaves the artificial signal because it does not detect the real signal, the display will present 2 simultaneous signals. The sonar man may not detect both signals, if his attention is fully occupied by the first signal which he detects. When he happens to detect the artificial signal first, he may miss the real signal unless he is on the look out for more than one signal. Thus he must be warned to expect more than one signal at a time.

34. If the sonar man detects the real signal first, there is only a small chance that it will be confused with the artificial signal. For confusion to occur, the 2 signals must have about the same range and bearing. Though possible, this is unlikely to happen very often. If the artificial signal is switched off as soon as the computer is interrogated, the presence of the real signal in the same position should then be noticed by the sonar man. This is because he will use the criterion of disappearance of the signal to decide whether the signal is real or artificial. If he sees that the signal remains on the display after he has interrogated the computer, he will know that it represents a real target. He will then follow the procedure which is laid down for reporting real targets.

35. A minor problem in the use of artificial signals may occur if the officer in charge decides to stop the injection of artificial signals for a while. He may do so if he expects signals from a number of real targets. In Figure 1 the probability of detecting real signals falls almost as soon as the artificial signals are removed. Officers need to be warned of this possibility.

Computer assistance as a substitute for knowledge of results

36. Computer assistance is an alternative method of combating fatigue during sonar work periods. In the experiment by Hartley, Olsson and Ingleby (1972) in Table 1, a group of 16 enlisted men receives assistance from a computer. Two seconds before each noise burst which may contain a tone signal, a display indicates whether the computer has detected a signal. The computer uses 6 degrees of confidence, from certain signal to certain no signal. The computer is correct on 75% of trials.

37. Without computer assistance, a control group detects reliably fewer signals in the second halves than in the first halves of the last 4 sessions. With computer assistance the decline in vigilance is small, and not statistically reliable. It is about one quarter the size of the decline without computer assistance.

38. The vigilance of the computer does not change. If the man follows the computer, his performance should not change either. The small drop in the number of correct detections presumably occurs on trials when the man fails to follow the computer. It is not yet known whether the decline in vigilance can be prevented by a computer which is less often correct, say on only 65% of trials instead of on 75%.

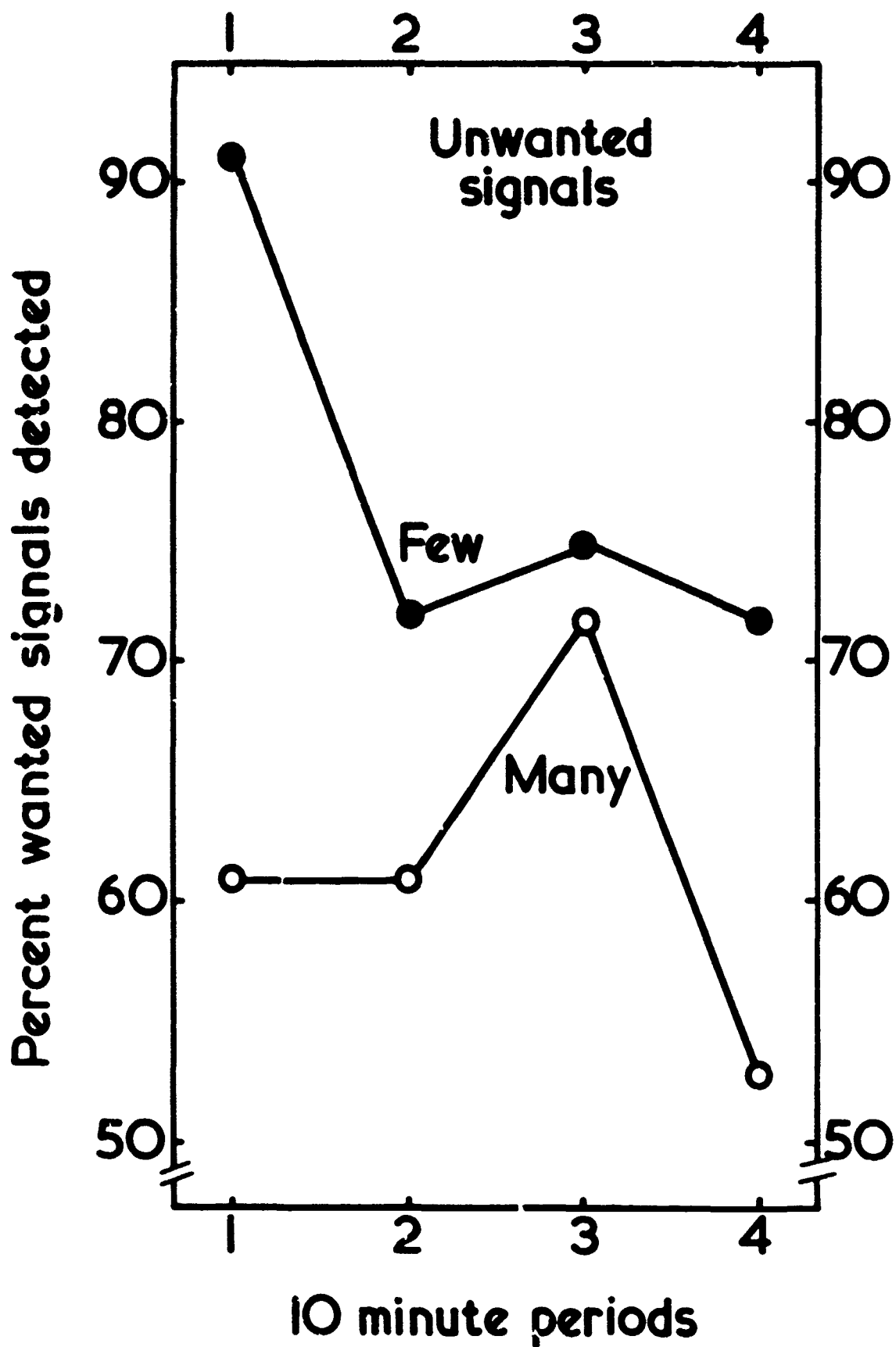


Figure 2

Figure 2. The effect upon the detection of wanted or target signals of presenting many unwanted sets of signals. The filled points represent the results of a control group of 12 enlisted men which receives 12 sets of unwanted signals, and 12 sets each containing a wanted or target signal. The unfilled points are for a separate group of men which receives 132 sets of unwanted signals, and 12 sets each containing a wanted or target signal. (After Colquhoun, 1961).

Computer assistance with changes in criterion

39. It might be thought that when there are no obvious signals, the computer should adopt a less cautious criterion. It will then indicate signals when they are less likely to be targets. An experimental simulation of this question has not yet been attempted.

40. Indicating less likely targets may not be found to improve detection. The less likely targets may have a similar effect to Colquhoun's (1961) unwanted visual signals, which is illustrated in Figure 2. In the condition with few unwanted signals, each of 12 enlisted men are presented with 24 sets of 6 visual signals. Twelve of the sets each contain one target signal. The remaining 12 sets do not contain a target signal. The total of 24 sets are distributed at irregular intervals during the 40 minutes of the experimental period. The display is blank for 98% of the time. During this time the man can relax.

41. In the condition with many unwanted signals, a separate group of men are presented with 144 sets of 6 visual signals. Again 12 sets each contain one target signal. But here there are 132 sets which do not contain a target signal, 11 times as many as in the previous condition. The display is blank for 88% of the time. The difference in height between the 2 functions is reliable statistically. In both conditions about 3% of the unwanted signals are reported as targets.

42. Colquhoun's unwanted sets of signals reduce the proportion of detections, instead of increasing it. The effect is in the opposite direction to the effect of Wilkinson's (1964) identical artificial signals with knowledge of results on them. This is because Colquhoun's extra signals are unwanted. The man becomes used to rejecting them. Probably as a result, he rejects more real target signals when they do appear. The results have been confirmed since by Jerison, Pickett and Stenson (1965), and by Loeb and Binford (1968).

43. The experiment suggests that it may be unwise for the computer to change its criterion from the optimum when it fails to detect any signals for a while. If it is wished to keep the sonar man alert, it would appear preferable for the computer to insert identical artificial signals from a store of typical signals, and present knowledge of results on them. As already indicated, the signals could help to train the man at sea, as well as helping to keep him alert.

Mild stresses which reduce or increase vigilance

44. Vigilance tasks which resemble sonar work are particularly susceptible to stress. This is because the tasks are prolonged and boring. Vigilance tasks are therefore standard tasks to use in assessing the influence of relatively mild stresses upon work (Wilkinson, 1969b). There are a number of experiments which illustrate the effects of various stresses upon vigilance tasks. Experiments which give reasonably unambiguous results are listed in Table 2. Not all the stresses are detrimental. An

uncomfortably hot sonar cabin with a bit of noise may help to maintain vigilance.

45. The experiments upon reduced sleep and watchkeeping towards the top of the table, are based upon relatively long series of work sessions. So are the experiments on the effects of fever. Most of the remaining experiments in the table are based upon the minimum number of sessions which are required to compare the various experimental conditions.

46. There are 2 disadvantages of short experiments, which limit the generality of the results. First, as already pointed out, the task is not well practised. It is not possible to tell whether the task will be more or less affected by the stress when it is performed by people who are better practised. All one can conclude with reasonable certainty is that the task is likely to be affected to some extent.

47. The second disadvantage of short experiments is that the people are not used to the particular stress. This criticism does not apply to the experiments on heat in Table 2, because in both experiments the men are well acclimatized before testing starts. But the criticism does apply to the remaining short experiments in the table.

48. There is some evidence (Wilkinson, 1969b) that people who are used to a particular detrimental stress tend to perform better under the stress than people who meet the stress for the first time. There are a number of reasons for this (Poulton, 1970, page 34) which will not be discussed here. It means that the detrimental effects reported in the table for unacclimatized people may be less marked for acclimatized people. But it seems unlikely that the effects will disappear completely upon acclimatization.

49. With detrimental stresses, the unacclimatized sonar man should be the typical person. Permanent detrimental stresses can usually be avoided. This is particularly important for the sonar man, because sonar is so easily affected by stress. It should be only in exceptional circumstances that the sonar man is exposed to detrimental stresses which can be avoided.

Avoiding loss of sleep

50. Table 2 shows that a sleep debt of about 5 hours reliably reduces vigilance. A sleep debt is cumulative. The effect is much the same whether the 5 hr are lost on a single night, or whether fewer hours are lost on each of 2 or 3 consecutive nights. If a sonar man spends part of the night awake on watch, he should be given compensatory sleep the next day before coming on watch again.

51. In the second section of the table, loss of sleep is probably partly responsible for the reduced vigilance at 05.00 hr on the rotating watch. The men work the previous evening from 20.00 to 24.00 hr, and come on watch again at 04.00 hr. This means that they probably have a sleep debt of about 5 hr when they come on watch at 04.00 hr, because part of the 4 hr break is taken up with getting to and from their sleeping quarters, having a snack, and so on.

52. The result indicates that a sonar man who works the second half of the night, should not work late the evening before. The time should be spent in going to bed early, in anticipation of the early rise the next day.

53. Unfortunately this still leaves the problem of the low level of vigilance on first waking up, which is discussed in the next section. If the sonar man gets up a few hours before he comes on duty at 04.00 hr, he misses most of the night for sleeping. To

compensate for this, he needs to sleep in the late afternoon and evening. It is not an easy time to sleep, unless a man is used to it. Getting men used to sleeping at unconventional times of the day, means introducing a stabilized watchkeeping system.

Reduced vigilance at the start of the working day and after a heavy lunch

54. Unfortunately it is not possible to compare the overall levels of performance of the watchkeeping experiments listed towards the top of Table 2. This is because the tasks performed are not comparable. But there is an important conclusion which can be drawn from the experiments with stabilized watches. This is that after acclimatization, vigilance tends to be low at the start of the working day at whatever time in the 24 hours it occurs. Vigilance also tends to be low after a good lunch.

55. There are quite simple ways of counteracting these undesirable effects. The sonar man should get up an hour or two before he starts his watch. And the heavy meal of the day should be taken after work, not just before a watch.

Increased vigilance when a little too hot for comfort

6. Table 2 shows that acclimatized men are most vigilant at an effective temperature of about 27°C (80°F), when dressed only in shorts. This corresponds to an air temperature of about 31°C (88°F), with a humidity sufficient to give a wet bulb reading of 25°C (77°F), and a certain amount of air movement. Men are less vigilant in both hotter and cooler climates. They are more vigilant with a mild artificial fever, although not with a feverish illness.

57. This suggests that sonar rooms should be too warm rather than too cool. Perhaps an air temperature of 27°C (80°F) should be recommended for men dressed in shirts and trousers. However the results favouring warmth are based upon short tests with a relatively large number of signals. Except for the experiments on feverish illnesses, all the signals come from a single source. No visual search is involved. Clearly a final conclusion must await trials at sea, using sonar cabins with different temperatures.

Varied auditory stimulation increases visual vigilance

58. The first section on noise in Table 2 is concerned with the effect of continuous loud noise on visual vigilance tasks. Columns 3 and 4 show that noise at a sound pressure level of 100 or 95dB sometimes reduces vigilance and sometimes increases vigilance. This is because noise has 2 opposite effects upon performance. It reduces the efficiency of performance, but it does keep the man aroused and alert. In vigilance tasks the arousing effect is sometimes more important than the effect upon efficiency. This suggests that ship noises are not necessarily harmful to visual sonar work.

59. The third section on noise is concerned with varied noise, generally between 70 and 80dB. Varied noise is better than continuous unvarying noise when a man is performing a visual vigilance task. This suggests that the sonar man should not be kept isolated and quiet. He is more likely to remain alert in a cabin with other activities going on around him.

Motion sickness remedies

60. In rough weather the officer in charge has an unsatisfactory choice. He can have a sonar man who is inefficient because he is feeling and being sick. Or he can have a sonar man who is inefficient because he has taken a remedy for motion sickness which

depresses the brain. The experimental comparison needs to be carried out at sea in rough weather. It has still to be done. The only experiment of the kind yet to be performed, uses simple arithmetical additions as the task, and life rafts on artificial waves. The enlisted men perform better with the motion sickness remedies than without (Brand, Colquhoun, Gould and Perry, 1967).

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TABLE I. VIGILANCE EXPERIMENTS WITH REPEATED

Author(s)	Year	Nature of		Signals		Visual	Sec
		No signal	Signal	Duration (Sec)	No. per hour	Search	
Adams, Brown, Colquhoun, Hamilton, Oreborn, Thomas and Worsley	1972	0.6 sec tone every 3 sec	0.68 sec tone	0.68	60	No	30
Adams, Hume and Sievking	1963	36 letter Gs with possible changes every 4 sec	G changes to F	20	45	Yes	180
Adams, Hume and Stenson	1962	6 letter Gs with possible changes every 4 sec	G changes to F	20	45	Yes	180
Alluisi and Hall	1963	0.25 sec tone every 1.2 sec	Tone after 1.05 sec	0.25	8	No	240
Attwood and Wiener	1969	20° needle deflection every 1.2 sec	30° deflection	very short	40	No	48
C. H. Sawyer	1963	a. Continuous rotation of clock hand b. Continuous small deflections of needle	Brief hesitation Deflection to right at least 2.5 times as large	0.4 0.25	24 {	No	120
F. A. Baker, Sipowicz and Ware	1961	Continuous light	Brief interruption	0.03	24	No	90
Sinford and Loeb	1966	60dB noise pulse every 2.5 sec	6 1.8dB noise pulse	0.5	30	No	80
Buckner, Harabedian and McGrath	1960	1 sec light every 3 sec, or 1 sec 750 Hz tone every 3 sec (task alternation)	Slight increase in intensity	1	3 to 31	No	60
Carpenter	1946	0.75 cm jump of tip of needle every 1 sec	1.5 cm jump	very short	24	No	120
Colquhoun, Blake and Edwards*	1968a	Tones of 300, 500, 700 and 900 Hz with random amplitude modulation	Transient small increase in intensity	0.2	50	No	120
Colquhoun, Blake and Edwards	1968b	Continuous white noise	900 Hz tone burst	1	43	No	50
Colquhoun, Blake and Edwards*	1969a	4 tones and/or 4 small circles of light with random amplitude modulation (task rotation)	Transient small increase in intensity	0.2	30 or 45	Yes for visual and audiovisual conditions	96 (3x32 or 2x48)

SPACE EXPERIMENTS WITH REPEATED PROLONGED DAY SESSIONS

No. per hour	Visual Search	Sessions		Knowledge of results		No	People	Other Points	Changes within sessions after practice				g
		Duration (min)	No.	Immediate	Delayed				Deterioration		Increased caution		
							Kind		Detections	d'	BT	False detections	
60	No	30	24	No	No	12	Enlisted men		(results not available)				
45	Yes	180	10	No	?	12	Undergraduates				Yes		
45	Yes	180	10	No	?	12	Undergraduates				Yes		
8	No	240	4	No	No	25	Undergraduates	Additional tasks	Yes?				
40	No	48	5	No	No	17	Men under-graduates	Results from control condition only	Yes?				
24	No	120	5	No?	?	16	Houseswives		No				
						16		Yes?					
24	No	30	15	No?	?	19	US Army officers		(results not available)				
30	No	80	9	No?	Yes?	12	Under-	(1 criterion) for (3 criteria) responses	No	Yes		No	No
						12	graduates		No	No		No	No
3 to 31	No	60	32 (10 visual + 10 auditory)	No	No?	54	Enlisted men	(Visual display (Auditory display	Yes?				
24	No	120	6	No	Yes	10	Enlisted men		Yes?				
50	No	120	22	No	No	6	Enlisted men	(Day watch (Night watch	No		Yes?	Yes	
43	No	50	48	No	No	(11 (10 (10	Enlisted men	Day watch Night watch Morning watch	Yes?		Yes?	Yes?	Yes?
30 or 45	Yes for visual and audiovisual conditions	96 (3x2 or 2x48)	72 35	No	No	(10 (12	Enlisted men	Day watch Night watch	Yes?		Yes?	Yes?	Yes?

TABLE I. (Continued)

Author(s)	Year	Nature of		Signals		Visual Search	Session Duration (min)
		No Signal	Signal	Duration (Sec)	No. per hour		
Colquhoun and Edwards	1970	0 black discs each 0.65 cm diameter with 2.2 cm between centres 2 black discs 1 black disc	17% increase in area of one disc 9% increase in area of one disc	1.8	108	Yes No	40
Hartley, Olsson and Ingleby	1972	0.5 sec white noise burst every 15 sec	1,000 Hz tone in the noise burst	0.5	24	No	75
Hatfield and Soderquist	1969	70dB noise pulse every 2.5 sec	71.6dB noise pulse	0.5	60	No	90
Loeb and Binford	1970	70dB noise pulse every 2.5 sec	72.2dB noise pulse	0.5	1	No	60
Kallis and Samuel	1961	a. 43 rpm PPI showing clutter, and b. Continuous 75dB noise. (2 simultaneous tasks)	1.5 or 2 mm blip Three 83.5 Hz tone pulses repeated every 4 sec 1 dB more intense than previously	1.0 until detected	10 +10	Yes No	135 180
Ware, Sipowicz and Baker	1961	Continuous white noise	Brief interruption	0.03	24	No	90
Rebb and Wherry	1960	Continuous 200 Hz tone	Change to 180, 190, 210 or 220 Hz tone and back again	3	12 or 30	No	540
Wiener	1968	20° needle deflection every 1.2 sec	30° deflection	very short	40	No	48
Wilkinson	1964	0.5 sec tone every 3 sec	0.37 sec tone	0.37	8	No	60
Wilkinson and Edwards	1968	0.5 sec tone every 3 sec	0.37 sec tone	0.37	14	No	51 212

* A question mark after a Yes indicates that the change in performance may not be reliable.

* See Colquhoun (1966) for some of the experimental details.

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File	Visual Search	Sessions		Knowledge of results		People		Other Points	Changes within sessions after practice				
		Duration (min)	No.	Immediate	Delayed	No.	Kind		Deterioration	d'	PF	Increased caution	False detections
									Detections			False detections	p
	Yes	40	8	No	No	8	} Enlisted men		Yes				
	No					8			No			Yes	Yes
24	No	75	8	No	Yes	16	} Enlisted men	{ Control condition { Computer assistance	Yes			No	
						16			No			No	
60	No	90	10	No	?	9	Enlisted men		Yes	Yes		No	No
1	No	60	5	No?	Yes?	25	Undergraduates		Yes?		Yes?	Yes?	
10	Yes	135	} 5	Yes	?	} 24	} Enlisted aircrew	Visual task					
+10	No	180		Yes	?			Auditory task					
24	No	90	10	No?	?	20	Enlisted men		(results not available)				
12 or 30	No	540	5	No?	?	3	Enlisted men	Within session change confounded with time of day			Yes?		
40	No	48	6	No	No	13	Men under- graduates		Yes				
			5	Yes	No	20			Yes				
8	No	60	6	No	No	6	Enlisted men	Results free control condition only	Yes				No
14	No	53	48	No	Yes	11	Enlisted men		(results not available)				
		212	8	No	Yes	6							

TABLE II. EFFECT OF STRESS UPON

Stress		Comparison			Acclimat- -ization	Nature of vigilance task
		Better	Worse	Reliable		
Reduced sleep	Hours slept) No))	Listen for an occasional tone of slightly shorter duration than usual
	a. on 1 night	7.5 hr	2 hr	Yes		
	b. on 2 nights	7.5 hr	5 hr	Yes		
	c. on 3 nights	6 hr	4 hr	Yes		
Time of day or night	a. on shore	21.00 hr	08.00 hr	Yes?) Yes))	Listen for an occasional tone of slightly longer duration than usual
		21.00 hr	13.00 hr (after lunch)	Yes?		
	b. on rotating watch	17.00 hr	05.00 hr	?	No	See Table 1
		c. After getting used to a stabilized watch	End of working day	Start of working day	?	Yes
			End of working day	After lunch	?	Yes
	Heat	Effective temperature (ET) for men stripped to the waist	ET 25°C (76°F)	ET 18°C (65°F)	Yes) Yes))
25°C (76°)			30°C (86°F)	Yes		
28°C (82°F)			20°C (67°F)	Yes) Yes))	As above
28°C (82°F)			33°C (92°F)	Yes		
Artificial fever			Mouth temperature, of man in PVC suit	38.5°C (101.3°F)	36.5°C (97.7°F)	Yes

EFFECT OF STRESS UPON VIGILANCE

Nature of vigilance task	No. of Sessions per man	People		Authors(s)	Year
		No.	Kind		
Listen for an occasional tone of slightly shorter duration than usual) 60 48	19	Enlisted men	Wilkinson	1969a
		16	Enlisted men	Hamilton, Wilkinson & Edwards	1972
Listen for an occasional tone of slightly longer duration than usual	5	25	Enlisted men	Blake	1967
See Table 1	22	6	Enlisted men	Colquhoun, Blake and Edwards	1968a
See Table 1	(48 24	31	Enlisted men	Colquhoun, Blake & Edwards	1968b
		12	Enlisted men	Adam, Brown, Colquhoun, Hamilton, Orsborn, Thomas and Worsley	1972
See Table 1	24	12	Enlisted men	Adam, Brown, Colquhoun, Hamilton, Orsborn, Thomas and Worsley	1972
Watch clock second hand for an occasional double jump	1	20+23 20+24) Enlisted men	N H Mackworth	1961
As above	3	18			
Listen for an occasional tone of slightly longer duration than usual	16	12	Enlisted men	Wilkinson, Fox, Goldsmith, Hampton and Lewis	1964

Stress		Comparison			Acclimat- -ization	Nature of vigilance task	
		Better	Worse	Reliable			
Artificial Fever	Rectal temperature after exercising for 30 min in ET 35°C (95°F)	38.6°C (101.5°F)	37.5°C (99.6°F)	Yes	Partial	Watch for an occasional flash 30% brighter than usual	
Feverish illness	a. Rectal temperature 3 to 4 days after infection with Talaracemia (rabbit fever)	Before fever 37°C (98.5°F)	During) fever) 39°C (102°F)	Yes Yes	No No) Watch for:) 1. red warning li) 2. green light go) off) 3. amber lights s) blinking) 4. moving needle) chan'es average) position)	
	b. Rectal temperature 2 to 3 days after infection with Phlebotomus (sandfly) fever	37°C o (98.5 F)	39.2°C (102.5°F)	Yes	No		
		37.2°C (99°F)	38.3°C (101°F)	?	No		
Cold	In cold weather suit on open bridge of HMS Kent	Air temperature 3°C (36°F)		-1°C (30°F)	Yes	No	Watch for dim light between one of 2 p of bright lights
Noise	a. Continuous noise Noise from machinery	Intensity 70dB 100dB		Yes	No	Watch 20 dials for occasional needles danger mark	
	White noise	{ 100dB	75dB	Yes	No	Watch 3 flashing s lamps for an occas brighter flash tha usual	
			75dB	Yes	No	Watch 1 flashing s lamp for an occasi brighter flash tha usual	
		{ 100dB	70dB	Yes	No	Check 2 sets of wri digits for an occasional mismatch	
			114dB	Yes	No	Watch hands of 3 c for an occasional double jump	
	Noise with humped spectrum	83dB	114dB	Yes	No		
b. Intermittent noise every 5 sec	100dB	quiet (54dB cont- inuous)	Yes	No	Detect a different letter in a group 16 identical lette		

TABLE II (Continued)

Acclimatization	Nature of vigilance task	No. of Sessions per man	People		Author(s)	Year
			No.	Kind		
Partial	Watch for an occasional flash 30% brighter than usual	14	12	Enlisted men	Colquhoun & Goldman	1972
No	Watch for: 1. red warning light 2. green light goes off 3. amber lights stop blinking 4. moving needle changes average position	24	8	Enlisted men	Alluisi, Thurmond & Coates	1967
No		30	8		Thurmond, Alluisi & Coates	1968
No		30	16		Coates, Thurmond, Morgan & Alluisi	1969
No		30	8		Morgan, Coates & Rebbin	1970
No	Watch for dim light between one of 2 pairs of bright lights	2	16	Enlisted men	Poulton, Hitchings & Brooke	1965
No	Watch 20 dials for an occasional needle above danger mark	5	10	Enlisted men	Broadbent	1954
No	Watch 3 flashing strip lamps for an occasional brighter flash than usual	2	20		Broadbent & Gregory	1963
No	Watch 1 flashing strip lamp for an occasional brighter flash than usual	2	12		Broadbent & Gregory	1965
No	Check 2 sets of written digits for an occasional mismatch	1	6+6	Extraverted women undergraduates	Davies & Hockey	1966
No	Watch hands of 3 clocks for an occasional double jump	3	9	Under-graduates	Jerison	1959
No	Detect a different letter in a group of 16 identical letters	4	24	Under-graduates	Warner	1969

TABLE II (Continued)

Stress		Comparison			Acclimat- ization	Nature of vigilance task
		Better	Worse	Reliable		
Noise	c. Other noises	radio programme	none	Yes	No	Watch lamp for an occasional brief o period
		various noises 72dB	white noise 72dB	Yes	No	Watch flashing lig an occasional brig flash than usual
		radio conversa- tion	white noise ? dB	Yes	No	Watch clock hands f occasional double
		radio broadcasts 80dB	fan noise 50dB	Yes	No	Look for 3 success odd digits in a se of type-written di
Amphetamine	dl-amphetamine sulphate (benzedrine)	Dose (10 mg	none	Yes	No	Watch rotating nee an occasional bri
		(10 mg	none	Yes	No	Watch clock second for an occasional jump
	d-amphetamine sulphate (dexedrine)	10 mg	none	Yes	No	Listen for an occa noise pulse slight lower than usual
Remedy for motion sickness	l-hyoscine hydrobromide	None	1 mg	Yes	No	Check a set of ty written digits ag a heard set
Alcohol	70 ml of 90% alcohol (equivalent to 2 double whiskies)	None	70 ml	Yes	?	Check a set of ty written digits ag heard set
Hypoxia	Percent oxygen in air breathed (equivalent to various heights above sea level)	21% oxygen (sea level)	12% oxy- gen (5,000 m or 15,000ft)	Yes	No	Watch flashing li occasional bright flash than usual
		21% oxygen (sea level)	11% oxy- gen (6,000 m or 17,000ft)	Yes	No	
No smoking	No smoking for 20 hr by habitual smokers	Normal smoking	No smoking	Yes	Yes	Watch for periph visual signals & tracking

TABLE II (Continued)

Stimulus Condition	Nature of vigilance task	No. of Sessions per man	People		Author(s)	Year
			No.	Kind		
No	Watch lamp for an occasional brief off period	3	112	Enlisted men	Ware, Kowal & Baker	1964
No	Watch flashing light for an occasional brighter flash than usual	8	28	Enlisted men	McGrath	1963
No	Watch clock hand for an occasional double jump	1	15+15	Men undergraduates	Pooch & Wiener	1966
No	Look for 3 successive odd digits in a set of type-written digits	1	14+14	Undergraduates	Davies, Hockey & Taylor	1969
No	Watch rotating needle for an occasional brief stop	3	56	Housewives	J F Mackworth	1965
No	Watch clock second hand for an occasional double jump	3	24	Enlisted men	N H Mackworth	1961
No	Listen for an occasional noise pulse slightly louder than usual	4	24	Students	Loeb, Hawkes, Evans and Alluisi	1965
No	Check a set of type-written digits against a heard set	2	11+11	Enlisted men	Colquhoun	1962
No	Check a set of type-written digits against a heard set	3	11+11	Enlisted men	Colquhoun	1962
No	Watch flashing light for occasional brighter flash than usual	4	20	Enlisted men	Cahoon	1970a
No	Watch flashing light for occasional brighter flash than usual	6	18	Enlisted men	Cahoon	1970b
No	Watch for peripheral visual signals while tracking	2	24	Habitual smokers	Tarriere & Hartemann	1964